Factorial analysis on forest canopy density restoration in the burned area of northern Great Xing'an Mountains, China

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Abstract: The restoration of forest landscape has drawn much attention since the catastrophic fire took place on the northern slope of Great Xing'an Mountains in 1987. Forest canopy density, which has close relation to forest productivity, was selected as a key factor to find how much the forest quality was changed 13 years after fire, and how fire severity, regeneration way and terrain factors influenced the restoration of forest canopy density, based on forest inventory data in China, and using Kendall Bivariate Correlation Analysis, and Distances Correlation Analysis. The results showed that fire severity which was inversely correlated with forest canopy density grade was an initial factor among all that selected. Regeneration way which did not remarkably affect forest canopy density restoration in short period, may shorten the cycle of forest succession and promote the forest productivity of conophorium in the future. Among the three terrain factors, the effect of slope was the strongest, the position on slope was the second and the aspect was the last.

Keywords: Forest fire; Burned area; Productivity restoration; Forest canopy density; Factorial analysis; Kendall correlation analysis
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Introduction

Forest fire, as one of the important ecological factors in forest ecosystem, had drawn much attention long before (Garren 1943, Weaver 1951 and Gill 1975). Yet the study on forest fire had not developed broadly in China before 1987. The catastrophic fire in the Great Xing'an Mountains in 1987 which brought an eco-calamity provided an opportunity to study the effects of large forest fire on forest ecosystem. Although a number of research achievements have been obtained since 1988 (Xiao *et al.*, 1988; Zhao 1988; Li *et al.*, 1988; Guan and Zhang 1989; Zhou *et al.*, 1994; Zhao *et al.*, 1994; Yang *et al.*, 1998;), there exist many deficiencies in this field, compared with international progress (Bergeron and Brisson 1990, Pianka 1992, Turner *et al.* 1997, and Grogan *et al.* 2000). First, most studies still were focused on the fire effect on one of the ecological factors such as vegetation, soil, hydrology, etc., and at fine scales. These studies lacked of comprehensive research which takes ecosystem as an integer at landscape or regional scale. Second, with the restoration of forest landscape in the burned area, a lot of research work has stopped since 1995, which results in discontinuity in this field.

The destructive fire on May 6, 1987 led to severe economic loss and enormous negative ecological effect. The anthropogenic disturbances after fire aggravated the complexity and uncertainty of the forest ecosystem succession (Nakagoshi 2001; Luo 2002; Wang and Li 2003; Kong *et al.*, 2003). Therefore the research on restoration of forest in the burned area especially on the function restoration at coarse scale should be continued. Forest productivity is an elementary index of the forest ecosystem function which can evaluate how the forest grows (Liu and Fu 2001). The forest canopy density which is one of the important indexes reflecting forest productivity as well as a key statistic data in forest inventory in China was selected as the research object in this paper. The main aim this study is to reveal the relationship between the restoration of forest function and influential factors using forest spatial data in 1987 and 2000. Considering the interaction between anthropogenic and natural factors, the regeneration ways (which were sorted as natural regeneration, artificial stimulating regeneration, direct seeding regeneration, planting regeneration) and terrain factors including slope, aspect and position were selected as influential factors in this paper besides fire severity, which was classified as lightly, moderately and severely burned.

Study area and methods

Study area description

Yuying and Fendou Forest Farms in the middle of Tuqiang Forestry Bureau on the northern slope of Great Xing'an Mountains were chosen as study area, which occupies 1 200 km^2 land area in total. Several reasons were taken into account for choosing the two forest farms as study area. First, 87.5% of the area was burned, which is convenient for the study of forest restoration at large scale. Second, topographical relief in this area is relatively steep, which is advantageous for the study of effects of terrain factors on forest restoration. Third, the natural regeneration assisted by human promotion and planting measures were taken after fire, which provides a chance to study the effect of human interference on post-fire forest restoration.

Tuqiang Forest Bureau lies in the northwest of Great Xing'an Mountains, at upper reaches of Heilong River, and belongs to Mohe County, Heilongjian Province. Geographic coordinates are between longitude 122°18′05″–123°29′00″ E and latitude 52°15′55″–53°33′40″ N. The average altitude is 500 m, with gentle undulating hills and open river valleys. The tendency of topography shows that the south is higher and the north is lower. Moreover, east slopes are steeper than west ones. This area has long and cold winter and short and hot summer. Mean annual

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temperature is -4.94 °C, with lowest temperature recorded at -53 °C. Mean annual precipitation is 432 mm, with relatively dry spring and winter, and moist summer and autumn. The main forest species are Xing'an larch (*Larix gmelimii*), birch (*Betula platyphylla*), pine (*Pinus sylvestris* var. *mongolica*) and aspen (*Populus davidiana*). Brown coniferous forest soil is the dominate soil genus with thickness of 10–30 cm.

Methods

Main data sources include forest inventory data (forest stand maps) of Tuqiang Forestry Bureau in 1987 and 2000, map of fire severity in 1987, management plan of Tuqiang Forestry Bureau, and field survey data.

Fire severity map in 1987 and forest stand maps in 2000 were scanned and digitized in ArcView3.3. forest canopy density (FCD) and various influential factors were extracted to generate distribution maps of FCD grade, fire severity, regeneration way, slope grade, aspect type and slope position respectively, according to criterion listed in Table 1 (attached figures).

Table 1. Criterion of various factors

Factors	Grade (type)	Attribute describe
	1	Non-stocked land or young growth and woodland which have not reached the statistic criterion
Forest	2	Canopy density 0–0.2 (including 0.2)
Canopy	3	Canopy density 0.2–0.4 (including 0.4)
density	4	Canopy density 0.4–0.6 (including 0.6)
	5	Canopy density 0.6–0.8
	6	Canopy density ≥ 0.8
	Lightly burned	Percentage of trees consumed by fire ≤ 30%
Fire severity	Moderately burned	Percentage of trees consumed by fire 30%–70%
	Severely burned	Percentage of trees consumed by fire ≥ 70%
	Natural regeneration	The generation completely depends on seed trees without any human measures
Regeneration	Artificial stimulating regeneration	Seeds come from seed trees, but rooting is assisted by wiping the litter away
way	Direct seeding regeneration	Artificially or aerially seeding
	planting regeneration	Directly plant young coniferous seedlings (*Larix gmelimii or Pinus sylvestris var. mongolica*)
	Flats	≤ 5°
	Gentle slope	5°–15°
Slope	Moderate slope	15°–25°
	Steep slope	25°–35°
	Sharp slope	≥ 35°
	Shaded aspect	North and northeast slope
	Semi-shaded aspect	Northwest and east slope
Aspect	Semi-sunny aspect	West and southeast slope
	Sunny aspect	Southwest and south slope
	No aspect	Dale and flat
	Valley	Area with gradients less than 5° and at the bottom of the catena
	Low slope position	Various aspects from piedmont to 1/3 height of mountains whose altitudes are less than 900m
Position	Middle slope position	Various aspects from 1/3 to 2/3 height of mountains whose altitudes are less than 900m
	Upper slope position	Various aspects from 2/3 height to peak of mountains whose altitudes are less than 900m
	Hill top	Area on top of mountains and higher than 900m

By overlaying the digital maps of fire severity, regeneration way, slope grade, aspect type and slope position type with the map of FCD grade, the effect of factors above on forest restoration were analyzed. Nonparametric Rank Correlation Analyses (Kendall Rank Correlation) was used to test the relationship between fire severity and area distribution of FCD grade. Distance Correlation Analyses (Similarity Matrix) were adopted to evaluate the effects of regeneration ways and terrain factors on the restoration of FCD. In order to normalize the difference in areas between various fire severities, regeneration ways, gradients of terrain factors, and distribution of FCD grades. We introduced relative area percentage expressed as: $P = A_{ij} / A_i$, where, A_{ij} is the area of the grade j in type or gradient I; A_i is the total area of type or gradient i. Data analyses were performed using SPSS10.0 and EXCELL.

Results and discussion

Changes of FCD grades

Two dominant FCD grades appeared in both 1987(pre-fire) and 2000 (Fig. 1). Grade 1 and grade 4 were the main grades pre-fire, while grade 1 and grade 3 were the main grades in 2000. Although grade 1 was the dominant one all the way, its area percentage reduced from 32.1% in 1987 (pre-fire) to 23.7% in 2000. This situation may be related to the strategies of afforestation in stead of harvest in suitable areas post-fire, which reduced the area of non-stocked. Another dominant grade dropped from grade 4 to grade 3, and area percentage increased from 7.6% to 39.6%, which showed that the forest was at the junior succession stage. Compared to those pre-fire, area percentage of higher FCD grades decreased distinctively, for example, area percentages of grade 5 and grade 6 decreased from 18.8% and 15.0% pre-fire to 8.1% and 0.1% in 2000, respectively. All the results showed that the level of FCD decreased compared to that of pre-fire, but the forest matrix had already formed, which can conduce to the further restoration of forest quality.

Fire severity and FCD

The area percentages of FCD grades in different fire severity areas in 2000 have changed distinctly compared with those in unburned area (Fig. 2). Among the three burn severities (lightly burned, moderately burned, severely burned), the curve of FCD grades in lightly burned area resembles the most to that in unburned area, while those in moderately and severely burned areas

were more similar to each other, with notable difference from that in the unburned area. In lightly burned area, the dominant grades were grade 3 and 4, occupying 68.9% areas; yet in unburned area grade 4 and 5 were the dominant grades, occupying 78.5% areas, while the area percentage of grade 1 increased by 11.4% compared with that in the unburned area, which indicated that the forest productivity in lightly burned area generally had already declined, and the area of non-stocked land or young growth below statistic criterion increased.

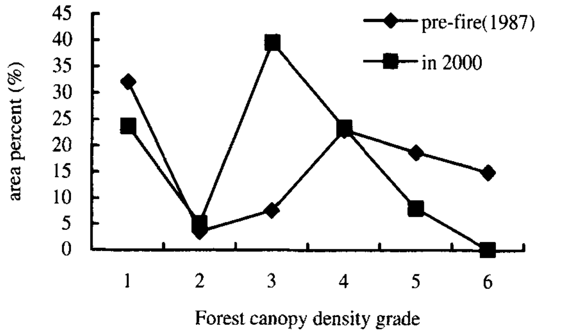

Fig. 1 Area percentage of forest canopy density grades (FCD) in 1987 and 2000 (the Criterion of FCD grade see Table 1)

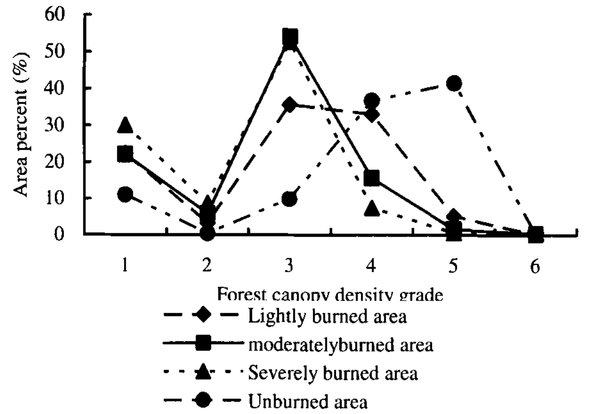

Fig. 2 Area percentage of forest canopy density (FCD) grades in different fire severities area in 2000
(the Criterion of FCD grade see Table 1)

The difference between maximum and minimum area percentage of FCD grades was 53.9% in moderately burned area and 52.5% in severely burned area, which was higher than that (41.6%) in unburned area. The area percentage of grade 1 in moderately and severely burned area was also higher than that in the unburned area. Although the area percentage of dominant grade (grade 3) in moderately and severely burned areas was above 50%, which is much higher than that in unburned area (9.9%), the area percentages of grade 4 and 5 were much lower than that in the unburned area. Such FCD grade composition showed that the productivity of forest post-fire in moderately and severely burned areas had greatly declined, and the difference of forest productivity had augmented.

This can be explained as follows: Firstly, because higher FCD grades often came from the survival trees after fire, and fire severity was closely related with tree survival rate, the loss was more in moderately and severely burned areas than that in lightly burned area. Secondly, the forest regenerated after fire at the same time almost had reached the third grade level. Along with the area percentage of this grade increasing greatly, the difference of area percentage of FCD among grades had expanded remarkably. Finally, in severely burned area, seed dispersal and recolonization were difficult, resulting in the increase of non-stocked land.

It is obvious that there exists a correlation between the area percentage of FCD grade and fire severity. We adopted Kendall Rank Correlation method to test further correlation. The result revealed a moderate significant correlation between fire severity and FCD grade in 2000 (tau-b=-0.422, $p<0.01$), which means fire severity had generated a negative influence on forest productivity.

The results above can be explained from the following aspects: First, the more severe the fire was, the more forest productivity was declined, and the more recovery time was required. As a result, there exists a negative correlation between fire severity and FCD grade. Second, considering the severe breakage of this catastrophic fire, restoration strategies including natural and artificial regeneration way were taken, especially in severely burned areas, where artificial regeneration way was completely adopted, and thus reduced the area percentages of coverage grade 1 and 2, which weakened the negative correlation between fire severity and forest productivity.

Regeneration way and FCD

Fig. 3 indicated that there was comparability in area percentage of FCD grade between regeneration way and fire severity, which can be attributed to post-fire management program. The natural regeneration was adopted in lightly burned area, areas of broadleaved under various fire severities and severely burned area with poor site condition, while human stimulating regeneration was introduced in moderately burned area, and severely burned area with good enough site condition.

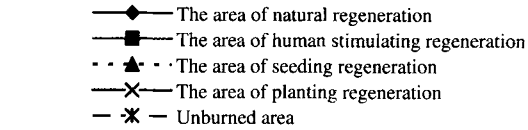

Fig. 3 Area percentage of forest canopy density (FCD) grades under different regeneration ways in 2000
(the Criterion of FCD grade see Table 1)

Distance Correlation analysis revealed that the similarity between FCD grades of post-fire regeneration ways and that of unburned area was very low. However, the similarity among various regeneration ways was significantly high. The highest similarity to unburned area was natural regeneration, but the value was only 0.398 (Table 2).

It seemed that artificial measures did not have effect on forest restoration. But this was not the true. 1) Regeneration measures were prescribed according to fire severity and site condition. The

area of natural regeneration mainly involved lightly burned area and broadleaved area, where a great number of trees survived, and broadleaved species have better germination ability. On the contrary, artificial measures were mostly used in severely burned area. Furthermore, the planted forest species was conifer with slow growth. Therefore the restoration of forest productivity in natural regeneration area was better than that in artificially restored area in short term. This also can illuminate that fire severity is the key factor which influences the forest restoration. 2) Artificial measures can exert important effect on restoration of forest landscape pattern. The area proportion of conifer in regions of artificial regeneration (direct seeding and planting) was higher than that of natural regeneration (natural and human promoted generation) in 2000 (Fig. 4), which greatly shortened the cycle of succession from broadleaved forest to conifer, especially in severely burned area (Wang 2003), and can significantly affect the productivity of conophorium at large time scale. 3) The high similarity of productivity restoration between natural regeneration and other regeneration measures in burned areas (Table 2) indicated that the selection of regeneration way was reasonable.

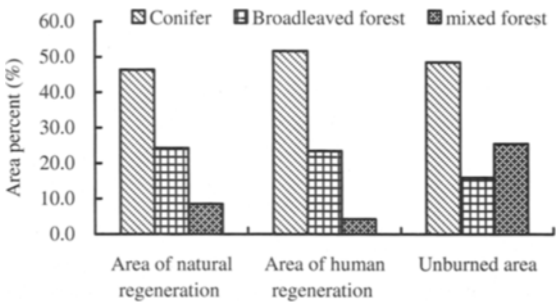

Fig. 4 Area percentage of forest types under different regeneration ways in 2000

Table 2. Similarity matrix of forest canopy density grade in areas under different regeneration ways and unburned area

	NR	HSR	DSR	PR	Unburned
NR	1.000	0.941	0.805	0.830	0.398
HSR		1.000	0.965	0.981	0.165
DSR			1.000	1.000	0.000
PR				1.000	0.108
Unburned					1.000

Note: NR--- Natural regeneration; HSR-- Human stimulating regeneration; DSR-- Direct seedling regeneration; PR--- Planting regeneration

Terrain factors and FCD

The influence of slope on FCD restoration

Distance analysis revealed that there was a significant correlation between area percentage of FCD grade and slope gradient in 2000 (Table 3), indicating that slope had significant influence on FCD restoration. The area proportion of FCD grade 1 on flats was 43.25%, which was higher than that on slope lands, but the trend for grade 4 and 5 was the other way around (Fig. 5 A). The main reason was that the proportion of swamp and brushes on flats was higher than those on slope lands by field survey, even in the forest land, due to the excessive soil moisture, trees do not grow better. Another reason was that the proportion of burned area was higher, especially that the area proportion of severely burned on flats was the highest among all the slope grades (Fig. 6 A), and limited the distribution of higher grades.

Table 3. Similarity matrix of forest canopy density grade on slope gradients

	FS	GS	MS	StS	ShS
F	1.000	0.420	0.271	0.221	0.000
GS		1.000	1.000	0.797	0.295
MS			1.000	0.948	0.517
StS				1.000	0.854
ShS					1.000

Note: F--- Flats; GS--- Gentle slope; MS--- Moderate slope; StS--- Steep slope; ShS--- Sharp slope

Area proportion of FCD grade 1 and 2 increased, yet that of grade 3 declined, and those of grade 4 and 5 increased too with the gradient increasing from gentle slope to steep slope (Fig. 5 A). Although the proportion of burned area and the fire severity decreased with the gradients increase, the proportion of FCD grade 1 and 2 did not decrease but showed increasing tendency. On the contrary, area proportion of grade 3 decreased with gradient increase. This pattern demonstrated that the lower the gradient was, the better the forest recovered on these slopes. Slope not only influences the angle of sun incidence and results in change of air and ground temperature, but also is the driven factor for the cycle of soil water and nutrient, which influences the thickness and physicochemical property of soil (Shen *et al.*, 2000). The more precipitous the gradient is, the more severe the soil erosion is, which leads to a poor forest restoration. The reason why area proportions of FCD grade 4 and 5 increased with slope gradient increasing was that survival trees increased with the proportion of burned area decrease and fire severity declination (Fig. 6 A). The area proportion of sharp slope was terribly small with only 0.035%, and located in lightly burned area (Fig. 6 A), where the proportion of grade 4 was comparatively high.

The Influence of aspect on FCD restoration

Distance analysis indicated that the similarities of area percentage of FCD grades among various aspect gradients were very high, with similarity indices all above 0.89, except no aspect land, which revealed that aspect had slight effect on restoration of forest productivity (Table 4). Due to the high proportion of swamp and shrub in no aspect land pre-fire, and global warming and anthropogenic disturbances, permafrost thawing and the expansion of forest wetland had a remarkable change (Zhou *et al.*, 2003), the area proportion of non-stocked land was high (Fig. 5 B). Shaded and semi-shaded, sunny and semi-sunny aspects were more similar respectively. Area proportions of FCD grade 1 to 3 in shaded and semi-shaded aspects were larger than those in sunny and semi-sunny aspects, while grade 4 to 6 presented opposite character. The reasons lay in two aspects: 1) Since proportion of burned area in sunny and semi-sunny aspects was larger than that in shaded and semi-shaded aspects (Fig. 6 B) and fire severity was more severe in sunny and semi-sunny aspects than that in shaded and semi-shaded aspects, area proportion of high FCD grades was decreased, while non-stocked land was higher in sunny and semi-sunny aspects. 2) Aspect exerts effect on site condition such as water and soil property through influencing sunlight condition. Sunny and semi-sunny aspects were drier in favor of birch, aspen which adapted arid condition (Xu 1988). As a result, the area proportions of FCD grade 3 in sunny and semi-sunny aspects land were obviously larger than those in

shaded and semi-shaded aspects.

Table 4. Similarity matrix of forest canopy density grade on aspect gradients

	SA	SSA	SSUA	SUA	NA
SA	1.000	0.993	0.944	0.940	0.006
SSA		1.000	0.906	0.894	0.000
SSUA			1.000	1.000	0.108
SUA				1.000	0.175
NA					1.000

Note: SA--- Shaded aspect; SSA--- Semi-shaded aspect; SSUA--- Semi-sunny aspect; SUA--- Sunny aspect; NA--- No aspect

The influence of slope position on FCD restoration

The similarity of area percentage of FCD grade between valley and other slope positions in 2000 was the lowest, while the highest similarity was found between middle slope position and upper slope position (Table 5). The largest area proportion of non-stocked land and no distribution of FCD grade 5 and 6 were discovered in valley (Fig. 5 C). High soil humidity in valley is the repellent force to broadleaved species such as birch, aspen, while the growth of conifer is retarded. Besides this, severe fire disturbance was another reason leading to large proportion of non-stocked land and low proportion of high grades (Fig. 6 C). Area proportion of FCD grade in middle, upper slope and hill tops existed obvious uniform constitute: grade 3, 4 and 5 were the preponderant grades occupying 84.5%, 90.8% and 94.5% respectively (Fig. 5 C). Good drainage condition and relatively dry soil in those positions were suitable for fast growing tree species such as birch and aspen, which promoted forest restoration.

Table 5. Similarity matrix of forest canopy density grade on position gradients

	V	LSP	MSP	USP	HT
V	1.000	0.491	0.003	0.000	0.000
LSP		1.000	0.867	0.866	0.848
MSP			1.000	1.000	0.982
USP				1.000	0.962
HT					1.000

Note: V--- valley; LSP--- Low slope position; MSP--- Middle slope position; USP--- Upper slope position; HT--- Hill top

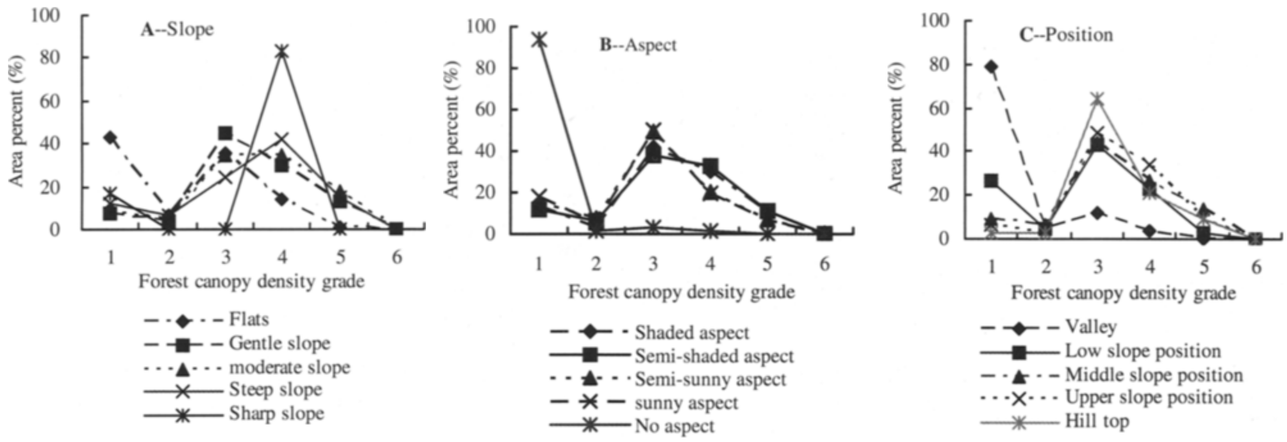

Fig. 5 Area distribution of forest canopy density grades on terrain (A, Slope; B, Aspect; C, Position) gradient in 2000
(the Criterion of FCD grade see Table 1)

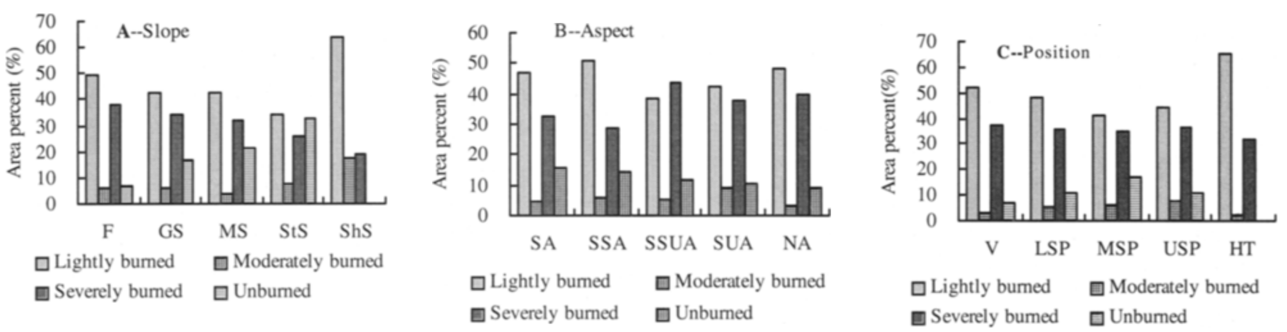

Fig. 6 Area distribution of fire severity on various terrain gradients (A. Slope; B. Aspect; C. Position)
Figure 6 A: F--Flats; GS--Gentle slope; MS--Moderate slope; StS--Steep slope; ShS--Sharp slope.
Figure 6 B: SA--Shaded aspect; SSA--Semi-shaded aspect; SSUA--Semi-sunny aspect; SUA--Sunny aspect; NA--No aspect.
Figure 6 C: V--Valley; LSP--Low slope position; MSP-- Middle slope position; USP--Upper slope position; HT--- Hill top.

FCD which has close relationship with forest productivity is an important index in forest inventory in China. Since the

method adopted was qualitative estimation, this important index was often misunderstood for the lack of precision. In fact, most foresters have rich experience, and the data came from field survey. Therefore the results should be credible and valuable.

Conclusion

The FCD which is one of the important elements of forest function has decreased notably. The FCD matrix were low FCD grades (grade 1, 2 and 3), while area percentage of high grades decreased a lot. Restoration of FCD thoroughly will need much time.

Fire severity was the initial influence factor on forest restoration, which determined the number of survival trees and seeding source. Even if seeding source can be complemented through artificial regeneration, survival tree rate still was the main factor that determined the area proportion of trees in good growth condition in a short time after fire. It was difficult to recover forest under poor site condition after severe fire. This kind of area can be changed into wetland or shrubs, resulting in the increase of proportion of non-stocked land in severely burned area. Though light burned area was completely naturally restored, the restoration status of forest was better than that in the moderately and severely burned area, where artificial regeneration measures were employed. Thus, fire severity was the key factor for the restoration of forest productivity.

Regeneration ways were human intervening factors in order to attain better restoration. The selection of regeneration ways were based on fire severity, site condition, and pre-fire species. Artificial regeneration supplied the seeding source, shortened the period from broadleaved to conifer, and restrained the degradation of forest land. Though artificial regeneration ways did not have obvious effect on forest productivity now, it was expected that restoration of conophorium productivity can be improved in the future 50-80 years.

Slope, aspect and slope position had all influenced FCD restoration, with slope as the most significant, and aspect as the least. Terrain factors exerted their influences on post-fire forest restoration mainly through influencing the intensity of fire and offering different site conditions. The area proportions of FCD grade in flats, valley and no aspect land had obvious difference from those on other terrain gradients, which was relative to larger proportion of wetland in this kind of area. Therefore probing into the evolvement of forest wetland will be of great importance on forest landscape restoration further.

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Attached Figures

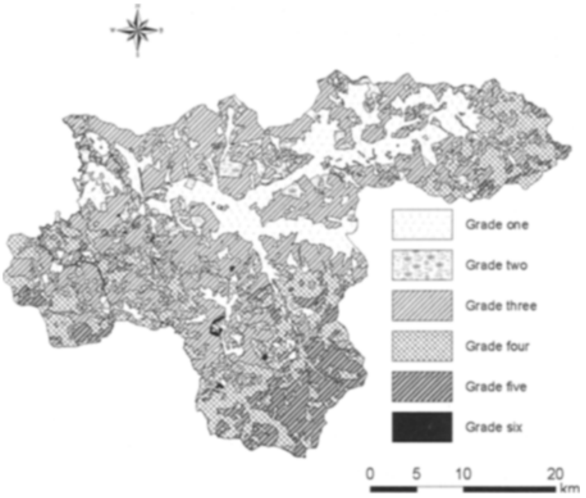

Fig.1 Distribution map of forest canopy density grades in 2000

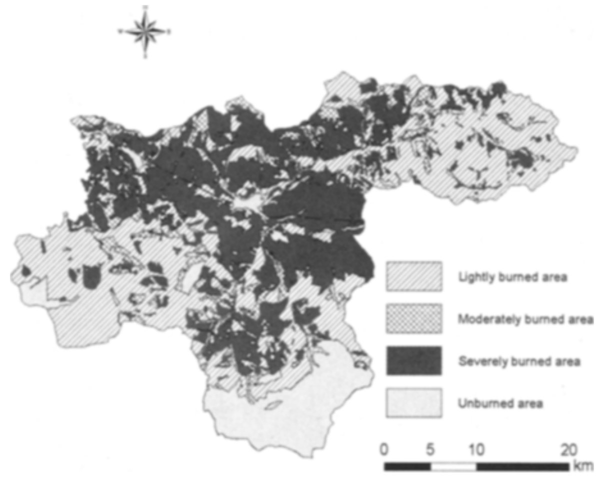

Fig.2 Distribution map of fire severities in 1987

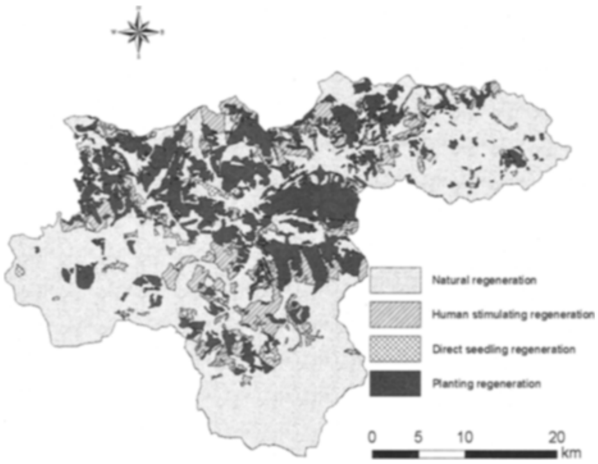

Fig.3 Map of regeneration ways after fire

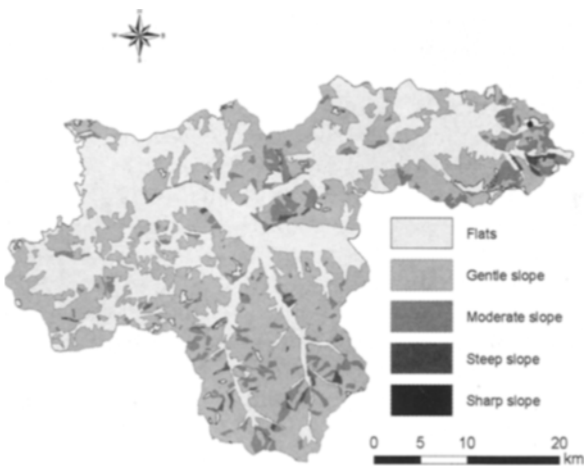

Fig.4 Distribution map of slope grades

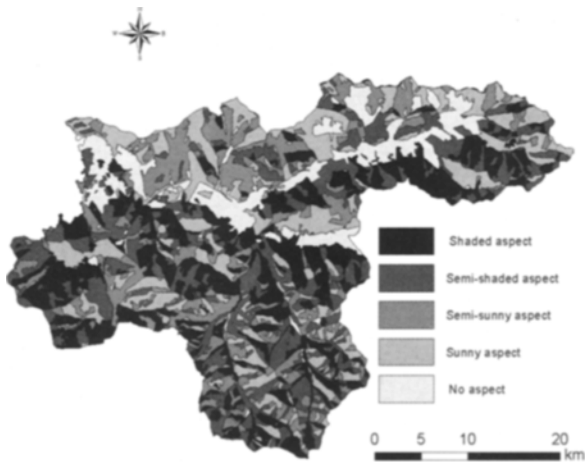

Fig.5 Distribution map of aspect types

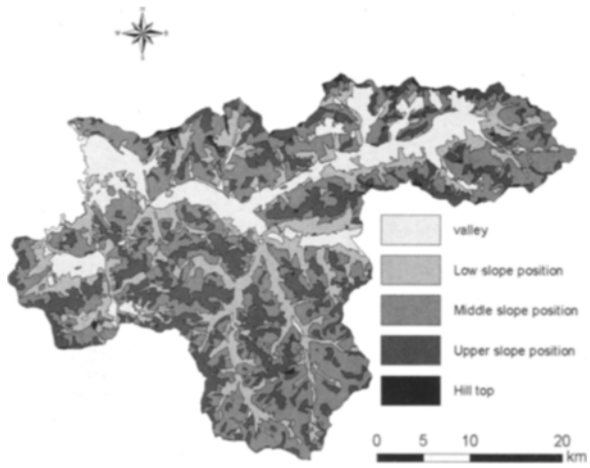

Fig.6 Distribution map of position types